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Target Ecological Limits and Not Economic Growth

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Abstract: Economic growth has both benefits and detriments for the sustainability of human flourishing. Economic growth has resulted in increased natural resource utilisation and discharges of emissions and wastes, which is worrying from a sustainability perspective. However, economic growth is intrinsically not a bad thing. It has many beneficial aspects, in particular the increasing supply of necessary goods and services that are needed to facilitate the flourishing of a growing human population. Furthermore, all types of economic growth are not necessarily impacting negatively on the natural environment. The key point is that global policy should not simply target economic growth with the aim of constraining it and striving for negative growth as a means to solving environmental sustainability concerns. This paper outlines the concept of ecological limits associated with natural resource utilisation and discharge of harmful emissions and wastes. It suggests that, instead of targeting economic growth, policies should target specific natural resource utilisation and emission discharge rates that exceed their ecological limits. Action plans should be developed and implemented using socioeconomic and technological approaches that try to bring these specific utilisations or discharges back to within their ecological limits. This may impact negatively on economic growth in the short to medium term but it is targeting specific resources and emissions that are unsustainable and the economic growth associated with them only. In the longer term, these actions may facilitate economic growth, while remaining within ecological limits.

Keywords: environmental sustainability; ecological limits; economic growth; degrowth

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1. Introduction

Economic growth has both benefits and detriments for the sustainability of human flourishing. Globally, economic growth is presently causing looming environmental crises [1,2], including climate change, biodiversity loss, water scarcity, land degradation, and nitrogen pollution. Economic growth has resulted in increased natural resource utilisation and discharge of emissions/wastes, which is worrying from a sustainability perspective, particularly in terms of environmental sustainability. There is a relationship between increasing gross domestic product (GDP) and greater environmental impact/unsustainability [3–5]. This suggests that the remedy is to lower GDP growth and move to GDP degrowth as the means to fending off the looming environmental crises, which requires a transition to a smaller economy with less production and consumption [6–10]. In addition to environmental aspects, there are other problems associated with the current form of economic growth, such as the social aspect of increasing inequality of income and wealth among individuals [11].

Economic growth is intrinsically not bad. In fact it has many good aspects to it, in particular, the increasing supply of necessary goods and services that are needed to facilitate the flourishing of a growing human population [12]. This makes economic growth potentially necessary to provide a bigger pie of goods and services to satisfy the needs of rising human populations. The benefits of the market economy and economic growth are quite bewildering in terms of the huge variety of products and services that are produced, better healthcare and education, poverty reduction, providing employment and work fulfilment for many, and the system's ability to inspire so many people to innovate, be creative, and facilitate their entrepreneurial capabilities. These benefits can be all too easily taken for granted. Furthermore, all types of economic growth are not necessarily impacting negatively on the natural environment. For example, some economic activities may use natural resources that are in abundance and not of concern from a sustainability perspective, or discharge wastes that are not having a significant negative impact on the environment.

In a similar vein to the above, Raworth [13] suggested that there are two sides to the debate on economic growth. There are those who believe that economic growth is a social and political necessity and that green growth with sufficient absolute decoupling can move natural resource use and emission discharges back to within planetary boundaries. Then, on the other side, there are those who believe that this green growth approach is not feasible, and there is a need for economic degrowth or a zero-growth economy [2,14,15]. Raworth suggested that there should not be such a focus on economic growth or degrowth; it is a matter of becoming agnostic about economic growth where it ceases to be the all-important goal [13,16,17]. Instead, the focus should be on developing a global economic system that exists with an ecological ceiling while providing a social foundation for everyone to flourish, which Raworth [13] referred to as "doughnut economics".

The work presented in this paper is in the area of environmental sustainability, which acts as a global life-supporting system and is a prerequisite to human sustainable development [18]. It is also the foundation for an economy that can facilitate the sustainability of human flourishing by sustainably supplying the natural resources required and sustainably dealing with wastes and emissions discharged by humanity. The motivation for this work is the fear that the current form of the global economy with a continuous drive for economic growth is environmentally unsustainable and has the potential to cause this economy to collapse at some point in the future. One approach to rectifying the environmental unsustainability is economic degrowth; however, this paper questions if a focus on degrowth is the best approach to tackling environmental unsustainability. A key assertion in this paper is that global policy should not simply target economic growth with the aim of constraining it and striving for degrowth as a means to solving environmental unsustainability concerns. Yes, there are major negatives associated with the current market system and the economic growth associated with it. Instead of targeting economic growth per se, policies should target these negatives more directly, in particular, the major environmental unsustainabilities, and find measures to overcome them. There are a variety of measures, such as legal, social, economic, corporate social responsibility, and technological tools that could all interact with each other to directly target and reduce the negatives associated with economic growth [19–21]. These actions will also impact on economic growth. They may cause degrowth, but they may also maintain it or increase it. However, appropriate measures should be implemented that tackle the negatives directly, and in a way that strives to minimise their detrimental impact on the positives associated with economic growth.

This paper summarises the concept of ecological limits associated with natural resource utilisation and discharge of emissions/wastes, as presented by the author [22]. The work presented here builds on this paper by suggesting that instead of targeting economic growth, there should be targeting of specific natural resources that are utilised and emissions that are discharged at rates that exceed their ecological limits. Action plans should be developed and implemented using socioeconomic and technological tools that try to bring these specific utilisations and discharges back to within their ecological limits. This may impact negatively on economic growth in the short to medium term, but it is targeting specific natural resources and emissions that are unsustainable and the economic growth associated with them only. In the longer term, these actions may facilitate economic growth.

The paper looks at fossil fuel energy, which is environmentally unsustainable from a resource utilisation perspective, but, in particular, from a greenhouse gas (GHG) emission perspective. Actions should be taken to reduce these; however, this is not currently happening at the scale required. The paper summarises work by William Nordhaus [23], which targets GHG gas emissions directly and provides an economic solution for stimulating the reduction of GHG emissions to within ecological limits. The paper considers conventional agriculture, where it applies ecological limits to directly target some of its environmental unsustainabilities and considers actions needed to restore the relevant utilisation and discharge rates to within ecological limits.

2. Ecological Limits and Assessing Environmental Unsustainability

There are different approaches to identifying and assessing environmental unsustainability problem areas. One approach is the application of ecological limits. A major aspect of environmental sustainability is that it needs the natural environment to continuously provide natural resources and to deal with its wastes continuously over time for humanity to sustain itself and prosper. Consequently, major aspects of environmental unsustainability are caused by:

- Unsustainable natural resource utilisation.
- Unsustainable discharge of wastes and emissions into the natural environment.

There are limits to the utilisation of natural resources and discharge of wastes/emissions if humanity is to continue to flourish over a prolonged period of time. These can be considered as ecological limits, and Fitzpatrick et al. [22] expressed these as limiting mass flow rates.

2.1. Ecological Limits of Natural Resource Utilisation and Discharge of Emissions/Wastes

The ecological limit of a natural resource (EL_{NR}) could be described as being equal to the rate of regeneration of the resource (RR). This is presented in Equation (1).

$$EL_{NR} = RR \tag{1}$$

An expression for RR is presented in Equation (2), where it can consist of a natural regeneration rate (RR_N), e.g., due to renewable resources, and a human regeneration rate (RR_H), e.g., due to recycling.

$$RR = RR_N + RR_H \tag{2}$$

Fitzpatrick et al. [22] argued that this definition of an ecological limit is potentially not feasible or too strict, and larger values could be applied while still remaining sustainable. They introduced the concept of a sustainable time perspective, whereby for a natural resource, this represents a time-frame or time duration such that the utilisation rate should not deplete the resource "stock" in less than this time. The sustainable time-frame could be chosen as to provide enough time for humans to adapt to the resource being depleted, e.g., the time for a number of human generations, such as 150 years. The inclusion of this this concept results in Equation (1) being modified to formulate Equation (3).

$$EL_{NR} = RR + \frac{Stock}{t_S} \tag{3}$$

where:

Stock: Mass of the resource present in nature that has potential for being extracted at some time in the future.
t_S: The sustainable time-frame for humans to adapt to the resource being depleted.

The ecological limit of a potentially harmful waste/emission to nature (EL_{WE}) could be described as being equal to the rate of assimilation of the waste/emission (AR). This is presented in Equation (4).

$$EL_{WE} = AR \tag{4}$$

An expression for AR is presented in Equation (5), where it can be both a natural assimilation rate (AR_N), e.g., due to CO_2 assimilation by plants, and a human assimilation rate (AR_H), e.g., due to carbon capture, sequestration, and utilisation.

$$AR = AR_N + AR_H \tag{5}$$

Like the natural resource ecological limit, Fitzpatrick et al. [22] argued that Equation (4) could be an unrealistic ecological limit or too strict a definition of an ecological limit, and that the ecological limit could be larger. They applied a similar analysis to the discharge of emissions/wastes, where there is an emissions "budget" instead of a stock. Similar to the natural resource ecological limit, a sustainable time-frame could be chosen as to provide enough time for humans to adapt to the budget being depleted, e.g., 150 years. Thus, even if the emission discharge rate is greater than AR, it could be considered sustainable if the budget lasts for more than the sustainable time-frame. The inclusion of this concept results in Equation (4) being modified to formulate Equation (6).

$$EL_{WE} = AR + \frac{Budget}{t_S} \tag{6}$$

where:

Budget: This is the mass of component that can be absorbed into the environment (or compartment within it), which increases the current concentration of the emission in the environment up to an agreed "onset of harm" concentration.

t_S: The sustainable time-frame for humans to adapt to the budget being depleted.

2.2. Application of Ecological Limits and Depletion Times as Warning Signals of Environmental Unsustainability

The above analysis can be applied to assess whether or not a natural resource or emission is environmentally sustainable at a specific time as follows.

For a natural resource, its rate of utilisation (RU_{NR}) is considered to be environmentally unsustainable if the Equation (7) is fulfilled.

$$RU_{NR} \geq EL_{NR} \tag{7}$$

i.e., its rate of utilisation is greater than its ecological limit. The rate of utilisation of a natural resource is the mass flow rate of the natural resource inputted into a human system, as illustrated in Figure 1a, which also shows that the rate at which the stock is being depleted equals RU_{NR} minus the rates of natural and human regeneration.

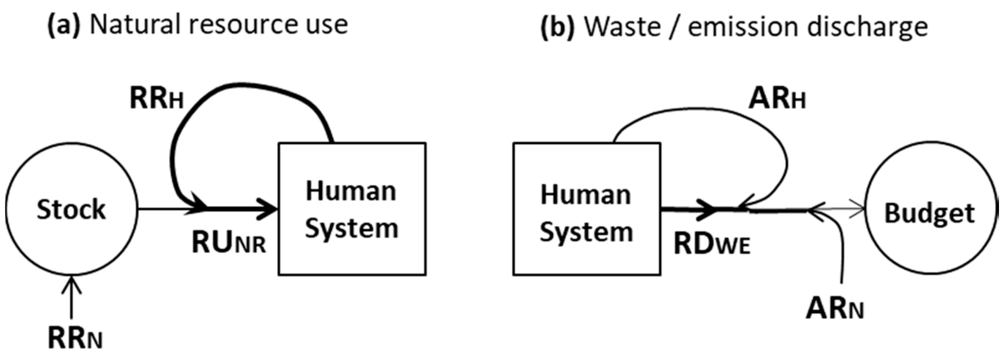

Figure 1. (**a**) Natural resource usage and its interaction with regeneration rates and stock; (**b**) Emission/waste discharge and its interaction with assimilation rates and budget.

Likewise, for a waste/emission, its rate of discharge (RD_{WE}) is considered to be environmentally unsustainable if the Equation (8) is fulfilled.

$$RD_{WE} \geq EL_{WE} \tag{8}$$

i.e., its rate of discharge is greater than its ecological limit. The rate of discharge of a waste/emission is the mass flow rate of the waste/emission leaving a human system, as illustrated in Figure 1b, which also shows that rate at which the budget is being depleted equals RD_{WE} minus the rates of natural and human assimilation.

Fitzpatrick et al. [22] presented an alternative approach using the above equations to assess the environmental unsustainability of natural resources and wastes/emissions. This approach manipulated the equations above to evaluate the depletion times of the stock of a natural resource or the budget of a waste/emission.

The time required to deplete the stock of a natural resource (t_{dS}) is given in Equation (9).

$$t_{dS} = \frac{Stock}{(RU_{NR} - RR)} \tag{9}$$

Likewise, the time required to deplete the budget (t_{dB}) of a waste/emission is given in Equation (10).

$$t_{dB} = \frac{Budget}{(RD_{WE} - AR)} \tag{10}$$

For a natural resource, its rate of utilisation is considered to be environmentally unsustainable if Equation (11) is fulfilled.

$$t_{dS} \leq t_S \tag{11}$$

i.e., its stock depletion time is less than the sustainable time-frame.

Likewise, for a waste/emission, its rate of discharge is considered to be environmentally unsustainable if Equation (12) is fulfilled.

$$t_{dB} \leq t_S \tag{12}$$

i.e., its budget depletion time is less than the sustainable time-frame.

Depletion times are a more intuitive and effective means of communicating to people whether or not natural resource utilisation or waste/emission discharge is environmentally unsustainable. Depletion times can act as early warning signals of environmental unsustainability of particular key resources and emissions. Figure 2 illustrates this by the application of a yellow/orange/red warning signal of the state of environmental unsustainability of a natural resource stock or waste/emission budget. In this example, the sustainable time-frame is given a value of 150 years. It is considered "Concerning" when the depletion time moves below 150 years, "Critical" when it moves below 50 years, and "CRISIS" when it moves below 25 years. The time values and words presented in Figure 2 are subjective and are given to highlight that lower depletion times are of greater worry and require more urgent action. Furthermore, the time values may vary between natural resources depending on their perceived criticality and substitutability. Likewise, they may also vary between wastes/emissions depending on their perceived harmfulness and importance of benefits associated with the goods/services that give rise to the wastes/emissions.

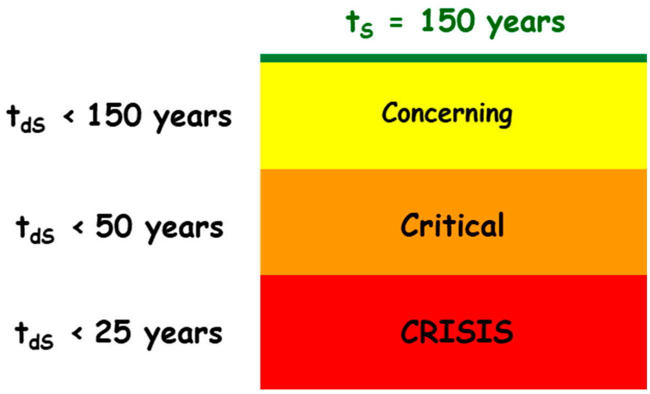

Figure 2. Depletion times (of natural resource stock or emissions budget) as warning signals of the state of environmental unsustainability.

2.3. Actions to Restore Utilisations and Discharges to Within Ecological Limits

Crucially, natural resource utilisation and emissions discharge rates that are greater than ecological limits and their corresponding depletion times act as a call for initiation of actions to be taken to restore sustainability when they move into the environmentally unsustainable domain.

For a specific natural resource, Equations (2), (3) and (7) highlight that this can be achieved over time by implementing the following:

- Decrease its utilisation rate, e.g., reduce resource demand or find substitutes for the resource.
- Increase its natural regeneration rate, e.g., increase the yields of renewable resources, such as agricultural yields.
- Increase its human-induced regeneration rate, e.g., improve the ability to increase recycling.

Likewise, for a specific waste or emission, Equations (5), (6), and (8) highlight that this can be achieved over time by implementing the following:

- Decrease its discharge rate, e.g., reduce GHG emissions by reducing the carbon footprint of the production of products/services.
- Increase its natural assimilation rate, e.g., increase the land area of forestry to assimilate carbon dioxide from the atmosphere.
- Increase its human-induced assimilation rate, e.g., assimilate carbon dioxide from the atmosphere by carbon capture, storage, and utilisation of carbon emissions.

These actions do not automatically occur themselves, although the onset of natural resource scarcity or negative economic impacts of severe pollution may cause the market to react and implement some of the actions highlighted above. For example, a resource scarcity can cause an escalation in market price, which can reduce demand for the resource or incentivise greater recycling. However, markets are typically short-termed and short-sighted and typically do not react sufficiently to an environmental unsustainability, with GHG emissions being a very good example of this. Furthermore, market economies have the potential to greatly undermine their ecological foundation and eventually collapse [24]. Consequently, other actions are required to induce the actions above for restoring resource utilisation or emission discharge rates to within their ecological limits. These actions are typically implemented through government policies. The major policy actions include the following [12,25]:

- Regulatory instruments
- Taxation
- Cap and Trade
- Subsidies

The dominant form of environmental policy globally is the application of regulatory instruments [25], such as bans of particularly dangerous substances, emissions limits, and technology standards. Policy makers favour this approach as they are familiar with it, and it is relatively cheap to implement. Economists believe that the taxation and cap and trade approaches provide the most cost-effective means of achieving the desired environmental goals [25], including the restoration of material flow rates to within ecological limits. These approaches can effectively increase the market price of natural resources and emissions discharges, which provides incentives to individuals and firms to reduce natural resource utilisation and emissions discharge rates [12]. Taxation directly increases price and uses this to control material flow rates, while cap and trade controls material flow rates directly by applying a quota and uses tradeable permits to determine price. The advantage of taxation is that it is simpler to implement, while the advantage of cap and trade is that it sets a quota, which directly specifies the material flow rates. Section 3 looks in more detail at the specific crisis of GHG emissions and the work of William Norhaus for reducing GHG emissions towards their ecological limit.

3. Targeting the Ecological Limit of Greenhouse Gas Emissions and "Nordhaus Economics"

Table 1 presents data from applying the ecological limits approach to GHG emissions for 1992 and 2017. It shows that GHG emissions were environmentally unsustainable in 1992, from a 150-year sustainable time-frame, with a GHG budget depletion time of around 65 years. Using Figure 2, this is not considered at crisis levels, but is concerning, bordering on critical. In the meantime, GHG emissions have increased from around 33 Gt $CO_{2\,eq}$ yr^{-1} in 1992 to over 50 Gt $CO_{2\,eq}$ yr^{-1} in 2017, and the budget depletion time was reduced to around 23 years in 2017, representing a crisis level in Figure 2. Fossil fuel energy is inherently unsustainable as it is the major contributor to the discharge of GHG emissions. It is also inherently unsustainable from a natural resource perspective; however, it will possibly take around 100 years to deplete the natural resource, thus this is less of a concern than GHG emissions [22].

Table 1. Environmental sustainability assessment of global greenhouse gas (GHG) emissions (t_S = 150 years) (units: budget–giga tonnes (Gt) of $CO_{2\,eq}$; AR_N, EL_{WE}, RD_{WE} – Gt of $CO_{2\,eq}$ yr^{-1}).

Year	GHG [1] Conc (ppm)	Budget [2]	AR_N [3]	EL_{WE}	RD_{WE} [4]	$\frac{RD_{WE}}{EL_{WE}}$	t_{dB} (years)
1992	378	1297	13.2	21.9	33.1	1.51	65.3
2017	454	706	20.3	25	50.8	2.03	23.2

[1] reference: [26]; [2] calculated from reference: [22]; [3] it is assumed that $AR_N = 0.4(RD_{WE})$; [4] reference: [27].

GHG emissions and their impact on climate change is one of, if not the most, pressing issues of the current century. GHG emissions are unsustainable and are far in excess of their ecological limit. Consequently, they need to be greatly reduced. One approach would be to target global GDP and greatly reduce it. This would indirectly reduce GHG emissions but would also greatly reduce the supply of goods and services, and thus human welfare. Other approaches are to try and target the reduction of GHG emissions more directly.

Professor William Nordhaus was the Nobel memorial prize winner in Economic Sciences in 2018. He is the author of a seminal book entitled *The Climate Casino–Risk, Uncertainty and Economics for a Warming World* [23]. This book presents a blueprint for the key role that economics can play in targeting the required reduction in GHG emissions more directly and consequently tackling the climate change crisis.

Nordhaus [23,28] poses the question of what will persuade billions of individuals, millions of firms, thousands of governments, and hundreds of countries to make the decisions and undertake the necessary actions to greatly reduce carbon/GHG emissions? This question appears to be extremely difficult to answer. Fortunately, he suggests there is a simple answer. The best approach is to use market mechanisms, and the single most effective market mechanism is PRICE, i.e., a high price on carbon emissions or high carbon price. He states that "people and firms must face economic incentives to tilt their behaviour towards low carbon activities. This is an inconvenient economic truth because people resist paying more for energy".

Nordhaus outlines that increasing carbon prices provides strong incentives to reduce carbon emissions through three primary mechanisms:

1. Higher carbon prices provide a signal to consumers about goods/services with higher carbon emissions that should be used sparingly or not consumed at all, e.g., air travel price increases, then less air travel use.
2. Higher carbon prices provide a signal to firms about inputs and their associated carbon emissions, which induces a move to lower carbon inputs.
3. Higher carbon prices provide market incentives for innovators and entrepreneurs to develop and implement lower carbon products/services, which moves society to a lower carbon energy paradigm.

Through Mechanism 3, innovators and entrepreneurs are incentivised to produce lower carbon products/services that are more economical due to the impact of rising carbon prices on increasing the price of higher carbon products/services. This enables Mechanisms 2 and 3 to function more readily as consumers and firms are economically incentivised to purchase these lower carbon products/services, and thus reduce their GHG emissions. These actions instigate a circular effect as a shift from higher carbon to lower carbon products/services shifts more investment and innovation/entrepreneurship towards lower carbon products/services, and this, in turn, incentivises consumers and firms to shift away from higher carbon to lower carbon products/services. These three mechanisms harness the power of the market to greatly reduce carbon emissions by altering people's behaviour to choosing lower carbon lifestyles and enabling low carbon-emitting solutions to compete economically in the market. This will most likely entail more affluent countries having to greatly reduce their energy requirements before renewables can deliver a major proportion of energy supply [29,30].

Nordhaus outlines that there are two mechanisms for implementing a price on carbon. These are carbon taxes and cap and trade schemes. He goes into much detail on the pros and cons of each, but ultimately it does not matter which is really used or if both are used, although he does favour carbon taxation because there is far less complexity to its implementation. What counts is that the pricing of carbon is implemented, and he provides an insight into how the price of carbon should be progressively increased over time. He highlights that free markets will not put a sufficiently high price on carbon. Governments will need to do this, consequently governments globally have a major role to play.

A critical facet to Nordhaus' approach is that carbon pricing must be harmonised globally in all countries and all sectors, as this is the most economically efficient way of achieving GHG emissions reduction targets and prevents free-riding. If the carbon price is different in different regions, then this causes a migration of high carbon sectors to low carbon price regions, thus these sectors are free-riding and not paying their fair share of carbon tax, which will negatively impact on reducing GHG emissions. Harmonisation on a global scale is necessary as averting dangerous climate change is a global problem requiring a global response. This results in the need for an international climate change agreement, or, as Nordhaus suggests, a "climate club" [23,31] that is a club of countries that implement at least the same minimum price on carbon over time. He goes into detail about this concept and how to deal with countries that do not initially wish to join and try to free-ride. His work also considers approaches to deal with the potential impacts of increased carbon prices on low-income countries and low-income people. Daly et al. [25] highlighted that one policy action, such as carbon pricing, can be targeted at mitigating an environmental issue like climate change, but may cause other problems such as fuel poverty, thus other policy actions are also required to address these other problems.

Another critical facet of Nordhaus' approach is the inclusion of economic cost/benefit analysis in the decision-making process for determining the target global temperature increase above pre-industrial times. Cost/benefit analysis is an approximate estimation of the global economic cost associated with mitigation measures required to achieve the target and the environmental damage cost. The mitigation cost greatly increases with lower target temperature increases, while the damage cost decreases at lower target temperature increases. Consequently, there is an economic optimum, or target temperature increase that minimises total cost (sum of mitigation and environmental damage). A 2 °C temperature increase is often presented as the desirable target. However, Nordhaus' work suggests that trying to stay within a 2 °C increase would be economically sub-optimal and a target of around 3 °C is where the economic optimum lies. This is inherently assumes that no significant climate tipping points have been passed.

This section briefly summarised Nordhaus' approach, referred to here as "Nordhaus economics", which more directly tries to target the unsustainable GHG gas emissions in an effort to reduce them towards their ecological limit. This will allow cleaner/greener approaches and technologies to compete with fossil fuels. It will direct increased investment, human resources, and innovation into a vast variety of ways to greatly reduce carbon emissions. This approach will most likely impact negatively on economic growth; it may cause global GDP to decrease in value due to increased energy prices as these cleaner approaches develop and improve. However, in the longer term, this may contribute to economic growth and increased GDP, while containing resource utilisation and carbon emissions to within ecological limits, due to the development of low carbon goods/services, energy conservation, improved energy efficiencies, and the development and implementation of cleaner energy.

This section has focussed on Nordhaus' approach to reducing GHG emissions. However, the concept of increasing the price of other harmful emissions or critical natural resources (through taxation and cap and trade schemes) can also be applied to controlling their material flow rates. More generally, the use of socioeconomic tools in combination with technology can be applied to other emissions and natural resources that are exceeding their ecological limits.

4. Targeting Ecological Limits in Conventional Agriculture

4.1. Conventional Agriculture and Environmental Unsustainability

Conventional food production currently produces a huge amount of food. It produces very high yields per hectare with typically good quality food. This has been accomplished by the use of mechanisation and energy from fossil fuels, fertilizers (in particular, nitrogen, phosphorus and potassium-based), pesticides and herbicides, irrigation to supply water, and high-yielding crop varieties that have been developed or genetically engineered.

In the longer term, conventional agriculture is potentially unsustainable [32,33] due to natural resource depletion and environmental degradation, as outlined below:

Dependence on natural gas and petroleum oil: Mechanisation, fertiliser and pesticide production heavily depend on petroleum and natural gas. Most agricultural machinery is powered by liquid fossil fuels, in particular, diesel. Nitrogen fertilisers, e.g., urea, are manufactured using natural gas. As these fossil resources deplete, so will the current model of agriculture/food production.

Depletion of Phosphorus: Phosphorus fertilisers are obtained from mining rock phosphate, but this is a limited resource and will deplete at some time in the future.

Water scarcities: Conventional agriculture uses a huge amount of water. Globally, about 70% of human water usage is used in agriculture. Currently, in many parts of the world, water shortage is limiting agricultural production. With global warming and climate change, this could be greatly exacerbated in some parts of the world.

Soil degradation: Conventional agriculture is gradually breaking down soil structures and depleting natural ecosystems and nutrient supply systems. The nutrients are being supplied externally through fertilisers. The net effect is that soils are being gradually converted from rich natural ecosystem/nutrient-rich systems into lifeless dirt [34].

Loss of resilience/biodiversity: Conventional agriculture depends on a small number of varieties to produce a major amount of world food, especially the grains. This dependence on a small number of varieties makes the global food system vulnerable to any factors that may negatively impact on these varieties, such as new diseases. This reduction in biodiversity reduces the resilience of the world food system to any major shocks.

Climate change: Agriculture is a major global contributor to greenhouse gas emissions. This is associated with carbon dioxide emissions associated with energy, nitrous oxide release from soils due to the breakdown of fertilisers, methane emissions from livestock production, and burning of forests globally for use in agriculture.

Some of these environmental unsustainabilities can be viewed from an ecological limits perspective, including GHG emissions [22]. This section explores this perspective and the actions that can be taken to move unsustainable natural resource utilisation and emissions discharge back to within their ecological limits.

4.2. Greenhouse Gas Emissions

As highlighted above, many of the GHG emissions in agriculture are associated with fossil fuel materials. From an environmental sustainability perspective, there are ecological limits to both resource utilisation and GHG emissions associated with combustion, with the latter being of most concern, being at crisis level. Consequently, actions need to be taken to reduce these emissions associated with agriculture.

In relation to energy supply, this is associated with liquid fossil fuels, in particular, diesel and also electricity. The ramping up of the price on carbon will impact agriculture. This will gradually change behaviour towards using less energy and for sourcing energy from non-fossil sources. This will be a major challenge as it will prove difficult to find a substitute for fossil fuel liquid used in agricultural machinery [29]; however, increased carbon prices will drive innovation to create solutions to these challenges.

In relation to nitrogen fertilisers, these are derived from natural gas. The general ramping up of carbon pricing will increase the price of natural gas, which, in turn, will increase the price of these nitrogen fertilisers. This will gradually change behaviour to using less of these. Higher nitrogen fertiliser costs may incentivise more efficient utilisation of nitrogen fertilisers, the use of alternative agricultural approaches such as agroecology [35], crop rotations with plants that naturally sequester active forms of nitrogen, precision fertilisation and sowing, and the use of GPS technology or the development of alternative technological approaches to producing nitrogen fertilisers.

A significant source of GHG emissions from agriculture is methane from ruminants, in particular, cattle. This can be significant in countries such as Ireland, where one third of the nation's GHG emissions is associated with beef and dairy production. Economic measures can also be applied here to influence consumer behaviour. For example, a carbon price can also be levied on net GHG emissions associated with ruminants (cattle in particular). This will increase the price of red meat derived from cattle, which will reduce demand and consequently reduce GHG emissions.

Nitrous oxide emissions is another significant source of GHG emissions from agriculture, mainly from the application of nitrogen fertilisers. Once again, economic measures such as a price on carbon can be taken to regulate the price of nitrogen fertilisers to take these emissions into account.

4.3. Fertilisers

The main fertilisers used in conventional agriculture are nitrogen, phosphorus, potassium, and sulphur. In relation to the environmental sustainability of nitrogen fertilizer, this is inherently intertwined with the targeting of ecological limits associated with methane production and global GHG emissions, which is highlighted in the previous section. As for the other components, sulphur is a common constituent of the Earth's crust and is thus not a limiting fertiliser for agriculture. Phosphorus and potassium fertilisers are obtained from mining rock phosphate and potash, respectively. Fitzpatrick et al. [22] highlighted that rock phosphate stock depletion time of economically viable reserves is about 90 years, which makes this concerning from the perspective of Figure 2, but not at critical or crisis levels yet. However, also considering currently non-economically viable reserves, the phosphate reserve base is much greater and its depletion time is of the order of 280 years. This perspective would make phosphate utilisation environmentally sustainable at this instance in time from a 150-year sustainable time-frame. For potassium, Fitzpatrick et al. [22] highlighted that the potash depletion time of economically viable reserves and the reserve base are about 230 and 500 years, respectively. Consequently, potassium is not of concern at the moment. However, both rock phosphate and potash are non-renewable resources and thus will become unsustainable at some point in the future. At some time in the future, their utilisation rate will exceed ecological limits and will become a concern, in particular, phosphate, and actions will need to be taken.

The above analysis has focussed on assessing environmental sustainability of fertilisers from a natural resource perspective and a GHG emissions perspective. Another important aspect in respect to the environmental sustainability of nitrogen and phosphorus fertilisers is highlighted by the planetary boundaries concept, which was introduced by a group of scientists led by Johan Rockström [36–38]. This work points out that a major amount of reactive nitrogen and phosphorus from fertilisers ends up in the natural environment, and that these discharge rates globally are well beyond planetary boundaries [38]. The planetary boundaries for nitrogen and phosphorus discharges are somewhat similar to the ecological limits of emissions considered here. Consequently, these works are suggesting that the nitrogen and phosphorus emissions are well beyond their ecological limits, and actions need to be taken to target these and reduce their emissions.

4.4. Water for Irrigation

Fresh water is a critical component in agriculture. In some parts of the world, this is mainly supplied by rainfall, while there is a need for irrigation to supply water in other parts. This water is supplied from surface waters (rivers and lakes) and groundwater (replenishable and non-replenishable aquifers). Ecological limits (presented in Section 2) can be nicely applied to aquifers to evaluate their environmental sustainability in terms of their stock depletion times. This can be used to provide advance warning of environmental unsustainability of the resource, such as in Figure 2, and the need for actions to be taken to reduce water utilisation. For non-replenishable aquifers, this will require a progressive reduction in water utilisation over time and eventually the resource will be depleted. For replenishable aquifers, this will also require a reduction in water utilisation, which will eventually reduce towards the rate of regeneration. In both cases, the reduction in water usage will require action to be taken to ensure these reductions.

For rivers, stock depletion times and a sustainable time-frame cannot be readily applied in a meaningful way as these are continuous flow systems. They do not really have a water stock like an aquifer. Rechargeable water (or natural water regeneration) rapidly moves through the system and is discharged to the oceans if not utilised by irrigation, for example. The ecological limit of the river is essentially the natural water regeneration rate, which is influenced by rainfall into the river basin and subsequent flow into the river, evapotranspiration losses and flows from seasonally melting glaciers and snow packs. The ecological limit will vary over time, depending on the season of the year. Furthermore, climate change may influence the ecological limit over years. Damming of rivers can be utilised to temporarily store water when water is in excess, so that this stored water can be utilised when demand exceeds supply. Overall, the ecological limit of a river and how it varies over time represent the maximum that can be obtained over time. Comparing utilisation rates to this limit gives an indication of how close demand is to the limit and if there is any potential for increased demand. If a river is operating at close to its ecological limit and there are significantly important new demands, then actions need to be taken to reduce existing demands so as to facilitate these new demands.

4.5. Impact of Economic Measures

Economic measures, such increasing carbon prices and fertiliser prices, are directly targeting natural resource utilisation and emission discharge that exceed their ecological limits. These measures will most likely cause food prices to increase and may cause crop yields to be lowered (due to lower fertiliser inputs), which could increase food poverty, and this is a real concern. As highlighted previously by Daly et al. [25], this requires the implementation of other policy actions targeted to address food poverty. This could include policies that require redistribution of income to lower-income people both within countries and between countries. Furthermore, higher food prices may incentivise the market and society to reduce food waste, as a major amount of food produced presently ends up as waste [33]. Higher food prices may cause lower food consumption overall, which is desirable in more affluent societies where problems with being overweight are more common. Increasing the price of red meat should reduce demand, and this may also provide opportunity for increasing food production by replacing red meat with foods that are more efficient suppliers of calories.

Of course, economic measures are not the only approaches; there are other approaches, including regulatory and cultural change, that may be applied to changing the agricultural development paradigm towards a more sustainable agriculture, such as an agroecology paradigm where there is potential to maintain high yields but which requires much more labour input to implement [35]. Ultimately, policy measures are required to tackle agricultural natural resource utilisations and emission discharges that exceed their ecological limits in order to avert a global agricultural crisis, as these will have to be addressed at some stage. It is easier to manage these in advance, before they enter their critical or crises stages, rather than to react to the impacts of an agricultural crisis.

5. Is There any Hope?

Is there any hope that approaches such as "Nordhaus economics" will be applied to averting looming environmental crises? Looking at the history of GHG emissions, one would say not really. The scientific community have highlighted the issue of GHG emissions and climate change for many years now. They started coming to prominence nearly 30 years ago, around 1992 with the Rio Earth Summit. Table 1 highlights the worsening environmental unsustainability of GHG emissions between 1992 and 2017. During this time, the scientific community, in particular the Intergovernmental Panel on Climate Change (IPCC), have done a very good job of trying to warn humanity about a looming climate change crisis. However, leaders in global society have chosen to ignore this warning or not to act at the scale required to tackle the crisis.

Presently, there does not appear to be any appetite for applying approaches like Nordhaus economics to tackling the looming environmental crises. It appears that "business as usual" will continue by and large until the severity of environmental change and degradation, such as climate change and natural resource depletion, causes major global economic disruptions, and that this is clear to many [39]. It is almost as if humans are genetically programmed to deal only with threats that they can physically sense or are financially affected by [40].

Mobilisation by younger people, for example, the Greta Thunberg movement, is possibly one ray of hope. Young people in their teens and twenties are starting to realise that climate change is worrying and could be kicking-in in the second half of the century (2050 onwards) when they will be middle-aged and getting older. Some are realising that major actions need to be taken very soon to avert possible misery for them in later life. This could become a real mobiliser for change and is a ray of hope.

6. Conclusions

The market economy is quite an amazing economic system that provides an unbelievable quantity and variety of goods and services globally. It harnesses the innovation, energy, and creative ability of a vast amount of people. It could be argued that economic growth is needed to provide the additional goods and services required to satisfy the welfare of an expanding human population. However, it is true to say that the current form of the market economy and its associated economic growth are giving rise to looming environmental crises, including climate change and many others. Consequently, it can be rightly argued that reducing economic growth and moving to economic degrowth is a valid approach to fending off looming environmental crises. The difficulty with this approach is that it will also affect provision of goods and services and employment, which will negatively impact on human welfare and the sustainability of human flourishing.

This paper argues that economic growth should not be directly targeted, i.e., the aim should not be to focus on economic growth directly with the intention of seeking economic degrowth. Instead, environmental unsustainabilities such as GHG emissions should be directly targeted. The ecological limits approach presented in this paper can be used to identify natural resources and emissions that are presently environmentally unsustainable, and to provide a warning signal of how concerning these are. Actions need to be taken to directly target the sources of environmental unsustainability and counter them. For example, economic approaches such as placing a price on emissions can be applied to stimulate the market economy to change human behaviour, and thus gradually reduce these emissions to sustainable levels. These actions will impact on GDP; they may cause a reduction, possibly degrowth, but these may in the longer run enable the market to change and grow in an environmentally sustainable manner, where natural resource utilisation rates and harmful emission discharge rates are maintained within ecological limits. In fact, if approaches like these can be implemented globally, they will unleash a bewildering amount of human innovation and creativity, which will find a vast variety of solutions to solving environmental unsustainability crises, while also developing and enabling a market to supply the goods and services required for human flourishing globally.

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